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PRIORITIZATION OF ES&H ACTIVITIES: A WASTE MINIMIZATION EXAMPLE*

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INTRODUCTION

Waste minimization and other ES&H activities at DOE facilities have increased significantly since the promulgation of DOE Order 5400.1, *General Environmental Protection Program*, and its implementation guidance (DOE 88a, DOE 88b)[1,2]. In addition to establishing requirements for reporting, training, and goal setting, DOE Order 5400.1 calls for increased emphasis on technology development for waste minimization. This call for technology development is echoed in the DOE "Environmental Restoration and Waste Management Five-Year Plan" and the subsequent *Applied Research, Development, Demonstration, Testing and Evaluation Plan* (DOE 89a, DOE 89b)[3,4]. As a result of this heightened emphasis on waste minimization, the DOE has received a large number of proposals from the operating facilities. Collectively, these proposals seek funding that exceeds the DOE budget. The large number and diversity of proposals that DOE must evaluate and prioritize increases the complexity of the proposal evaluation process.

Prior to this work, the existing DOE funding process began with the operating facilities submitting proposals to the appropriate DOE field office. Proposals describe the anticipated benefits of the project and the budget required for its implementation. Proposals are generally qualitative in nature (except for budget estimates) and are often returned to the operating facilities for additional information or clarification. The proposals were compared and evaluated by DOE headquarters staff using subjective judgment and were prioritized for funding purposes based on the perceived value of each proposal with respect to the agency's objectives. That system of evaluation and prioritization has become increasingly difficult to manage and defend because of the large and growing number of proposals that are submitted to DOE each year.

With these issues in mind, Sandia National Laboratories (SNL), with the support of ERC Environmental and Energy Services Company (ERCE), developed and demonstrated an enhanced proposal evaluation and prioritization process that can support DOE funding decisions. The evaluation and prioritization process outlined in this paper provides a defensible, auditable, and consistent method for selecting those waste minimization proposals that maximize the benefits to DOE while maintaining costs within the agency budget.

EVALUATION AND PRIORITIZATION METHODOLOGY

Six major steps constitute the overall evaluation and prioritization process:

1. Develop evaluation criteria,
2. Develop a project scoring system to account for quantitative and qualitative information,
3. Assign relative importance to the evaluation criteria and the scoring system,
4. Collect the proposal data,
5. Apply a prioritization technique, and
6. Optimize the allocation of funds to maximize the cumulative benefit.

Figure 1 illustrates how these major steps in the methodology are interrelated.

Evaluation Criteria Development

Evaluation criteria provide a means for organizing the various types of information describing proposed waste minimization activities. The criteria are organized in a hierarchy with the top-level criteria providing broad, logical groupings. These criteria are subdivided into lower-level criteria that have more focused areas of interest. Criteria are successively subdivided until a level is reached where individual answers from the data collection process can be introduced into the hierarchy through the proposal scoring system.

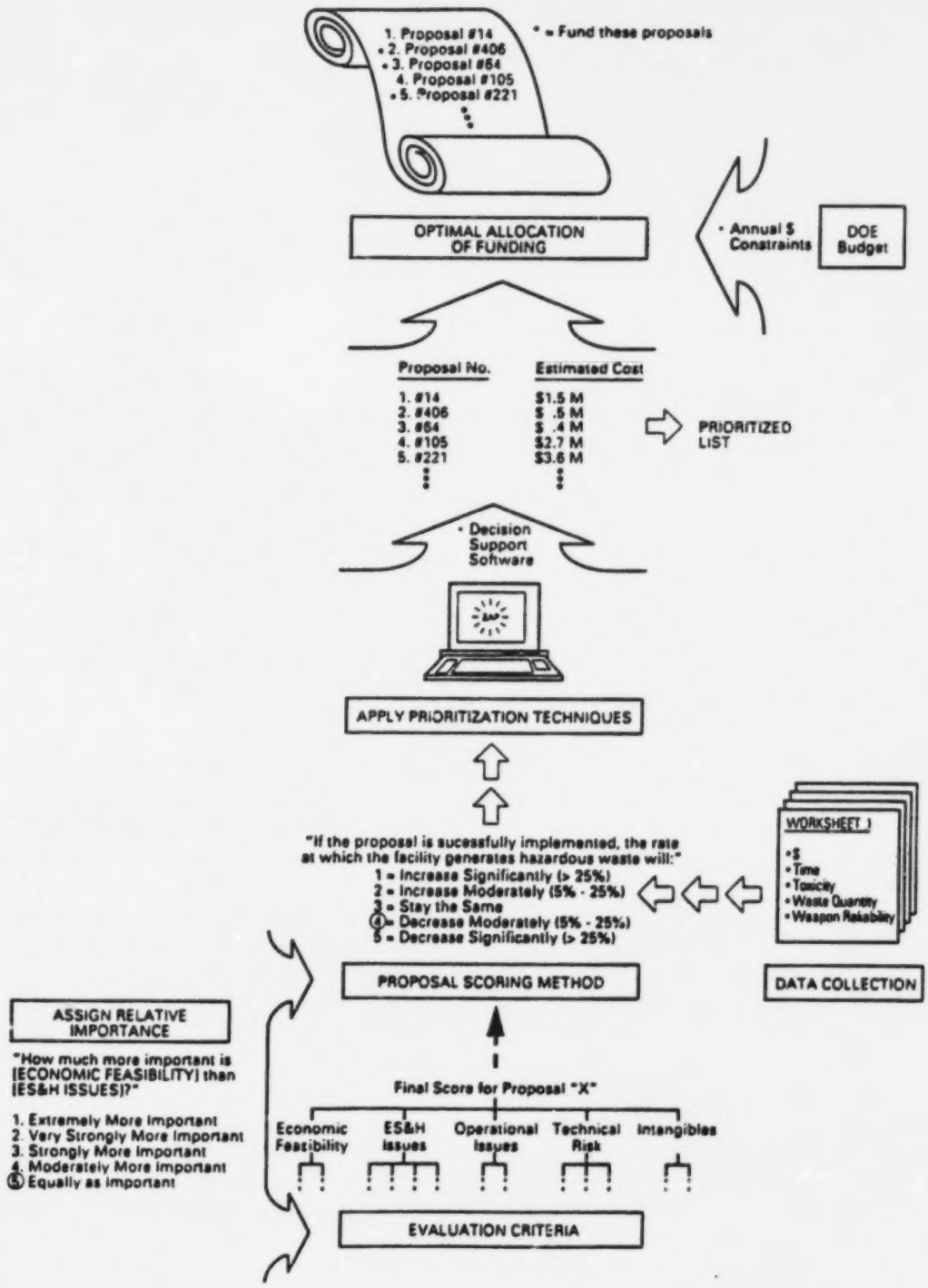

Figure 1. Evaluation and Prioritization Process

Five top-level evaluation criteria were used in the test case (listed in arbitrary order):

- Economic Feasibility,
- Effect on Environmental, Safety, and Health Issues,
- Effect on Operational Issues,
- Effect on Intangibles, and
- Technical Risk.

Three or four levels of more detailed criteria were developed under each top-level criterion. Although the top-level criteria may also be applicable to other technology areas (e.g., groundwater contamination, waste segregation, etc.), different lower-level criteria must be developed in order to apply the overall evaluation and prioritization method to other issues.

Proposal Scoring System

One of the difficulties in comparing a diverse group of proposed activities is translating data describing each proposal into common units so that rational comparisons can be made. Furthermore, if a scale does not exist to measure the "good" or "bad" that will result from a proposal's implementation, judgments about its value must be made in an arbitrary manner. The proposal scoring system presented here addresses these issues and provides a defensible method for translating both quantitative and qualitative data into comparable units. This system also provides a way to measure the positive and negative characteristics of a proposal.

"Summary findings" are used to measure each proposal with respect to the evaluation criteria. Summary findings are declarative statements about the lowest-level (terminal) evaluation criteria used to characterize a proposal. For example, if a terminal criterion addresses the rate at which a process generates hazardous waste, a summary finding is developed and applied consistently to all proposals to measure the proposed reduction in hazardous waste generation. A summary finding is developed for every terminal evaluation criterion in the hierarchy. Figure 2 presents an example of one of the summary findings used in the test case.

A total of fifty summary findings were applied in the test case application of the methodology. Responses to the summary findings (represented by whole number scores ranging from "1" to "5") are selected based on direct reference to specific quantitative data or a subjective interpretation of many different data items collected about a proposal. In all cases, the response "1" represents the worst possible outcome and "5" represents the best.

Assigning Relative Importance

Evaluation criteria and summary findings must be prioritized so that some attributes of proposals receive more importance than others. A decision maker addressing this issue must state clearly ordinal preferences for particular evaluation criteria and possible summary finding responses. For example, a decision maker may determine that the Economic Feasibility criterion is more important than the Technical Risk criterion, and so on. However, this ranking scheme does not address how much more important one evaluation criterion or summary finding response is than another. The concept of "relative importance" takes this important issue into account by indicating the difference between the evaluation criteria and the summary finding responses in ranked order (i.e., criteria "X" is 2.5 times more important than criteria "Y").

Assigning relative importance involves answering a structured set of comparative questions about the attributes of each proposal. The personal computer software program **Expert Choice** was used to help assign the relative importance to the evaluation criteria and summary findings for the test case. **Expert Choice** applies the analytic hierarchy process (AHP), a proven methodology for assessing the

Figure 2. Example Summary Findings Used in Test Case

If the proposal is successfully implemented:

The rate at which the specific process generates hazardous waste will: 1 2 3 4 5

1 = increase significantly (> 25%)
2 = increase moderately (5% to 25%)
3 = stay the same
4 = decrease moderately (5% to 25%)
5 = decrease moderately (> 25%)

relative merit of competing options. In the test case, all evaluation criteria and all possible responses to the 50 summary findings were weighted by the authors for illustrative purposes.

AHP is well suited for translating the opinions of a decision maker about a diverse set of topics into separate, numerical ratings that can be compared and combined into a figure of merit for each proposal. The **Expert Choice** program translates the pairwise comparisons that are made about each set of sibling evaluation criteria into numerical weighing factors. Likewise, the program calculates fractional scores for the summary finding responses. These weighing factors and fractional scores are the basis for assigning priority to competing proposals. (It should be noted that the AHP methodology used in the test case and, in particular, the **Expert Choice** program, is only one of several ways to assign relative importance to the evaluation criteria and to the summary finding responses.)

Data Collection

To characterize thoroughly the costs, risks, and benefits of the proposed waste minimization activities, quantitative and qualitative data should be collected. The data must address all important aspects of the waste minimization proposals and must be collected at an appropriate level of detail. More specifically, data must be collected that address the evaluation criteria and summary findings. The data collection process must also be auditable and demonstrate a clear path to the decisions that are subsequently made. Finally, data collection must be performed in a timely manner so that the usefulness of the entire evaluation and prioritization process can be preserved. Table 1 presents some of the quantitative and qualitative data that were collected or estimated in order to characterize the waste minimization proposals studied in the test case.

In the test case, data were collected at the DOE production facilities through a series of interviews with plant personnel responsible for the proposed waste minimization activities. Personnel from manufacturing, waste management, data management, and administration were interviewed to obtain a variety of information about the proposed activities. Laboratory personnel who have design responsibility for the facility components that will be affected by the proposed activities were also interviewed. General questions covering broad topical areas, such as "What effect will the proposed waste minimization activity have on hazardous waste generation?" and "What is the likelihood that the proposed activity can be successfully implemented?" were explored. The answers to these questions were recorded in logbooks. Later in the analysis, telephone conversations with plant personnel were used to

Table 1. Types of Data Collected in Test Case

QUANTITATIVE	QUALITATIVE
1. Cost to Implement Proposal	1. Effect on Weapon Reliability
2. Time to Implement Proposal	2. Effect on Weapon Safety
3. Volume of Hazardous Waste	3. Effect on Community Relations
4. Number of Workers Exposed	4. Likelihood of Success
5. Toxicity (lethal dose)	5. Applicability to General Industry
6. Activity (mrem/hr)	6. Operational Disruption if Proposal Fails

supplement the data collection process if clarification or additional information was required.

Prioritization Technique

Proposed activities are rated numerically by aggregating the fractional scores associated with each summary finding response and the weighting factors that were assigned to the evaluation criteria. All mathematical operations for the test case were performed automatically by the **Expert Choice** software program. This approach results in a score (or figure of merit) for each proposed waste minimization project. The score represents the cumulative benefit that a proposal will bring to DOE. Priority can be assigned by listing proposals in order from highest to lowest scores. Proposals with the same score can be arranged in arbitrary groups.

Optimal Allocation of Funds

Once a prioritized list of proposed waste minimization activities has been created, the final step is to allocate the available budget to the best set of projects. If the ultimate goal of the evaluation and prioritization process is to select, from a large and diverse set of waste minimization proposals, the set that maximizes benefits within a limited budget, all possible combinations of proposals must be considered before an optimal set is identified. (A corollary to this argument is that there is no inherent reason why the project with the highest figure of merit should always be selected for funding.) The method used to produce an optimal allocation of funds is a version of linear programming called "zero-one linear integer programming." Linear programming techniques are well understood and have been developed previously for DOE to allocate funding among competing projects.[5,6] These techniques are easy to use and can accomplish exhaustive computations rapidly.

To implement the linear programming approach for proposed waste minimization projects, four types of information are needed:

1. A score (or benefit measure) for each proposed project,
2. The overall budget for waste minimization activities,
3. The annual cost of each proposed project, and

4. An explicit description of the funding constraints that will be imposed on the process.

A single, comparable score for each proposed activity is necessary if the linear programming approach is to be used. Whether it is computed using decision support software or arrived at through the subjective judgment of the decision maker, the score of each project must ultimately be expressed in the same units (or as a unitless value).

The overall budget for waste minimization activities is another essential element in the linear programming approach to this problem. The budget should consist of all possible funding sources that will be used to support waste minimization projects. A total budget figure provides the fundamental constraint that cannot be violated.

Another type of information required for the linear programming approach is the annual cost to implement each proposal. Annual cost figures are necessary to allow a consistent means of comparing projects with widely dissimilar funding requirements. Describing projects by their annual costs also provides a way to measure the rate at which the anticipated benefits are introduced into the system. Assuming that the incremental benefit provided by a proposal is proportional to the incremental cost of the project, it is possible to subdivide the total benefit into annual portions that correspond to the annual cost. Thus, two proposed projects that have the same score and total cost to implement may not be assigned equal funding priority because of the timing of the costs and benefits.

Finally, it is necessary to know any additional funding constraints (other than the total budget limit) that must be observed. Additional constraints are explicit rules that must be met when the funding is allocated. For example, one constraint might be that the total funds allocated to basic research projects must constitute between 5 and 6 percent of the total budget. Another constraint might be that every facility must receive at least $1 million in funds. Of course, all constraints must be acceptable to the ultimate decision maker. Any number of funding constraints are acceptable, but each must be expressed in mathematical terms.

TEST CASE APPLICATION

Two research and development programs currently supporting changes to nuclear weapons manufacturing processes were investigated using the aforementioned methodology -- (1) the elimination of an acid rinsing process at the Rocky Flats Plant, Golden, Colorado and (2) the development and demonstration of a less hazardous potting material at the Pinellas Plant, Largo, Florida.

Rocky Flats Test Case Study -- Reservoir Rinsing

One of the major manufacturing activities at the Rocky Flats Plant is the production of stainless steel reservoirs and their connecting hardware. Reservoirs are produced by a series of turning, drilling, and grinding steps using standard machine tools. No nuclear material is used in these processes. Currently, reservoir components are rinsed using an automated immersion system consisting of several tanks containing nitric acid, hydrofluoric acid, aqueous detergent, and deionized water. The historical reasons for this multi-step rinsing process are to enhance the non-permeability characteristics of the stainless steel and to prepare the attached stem tubing for future welding operations.

Approximately 2000 gallons of concentrated acid (nitric and hydrofluoric) are discarded from this process annually. Furthermore, the deionized water in some rinse tanks quickly becomes contaminated with residual acid carried from bath to bath by the stainless steel components. The contents of these tanks must be continually replenished with fresh deionized water. This requirement leads to the creation of about 800,000 gallons of hazardous acid waste each year.

The waste minimization proposal at the Rocky Flats Plant is designed to determine whether or

not the nitric and hydrofluoric acids used in the rinsing process can be eliminated. The goal of this program is to demonstrate that rinsing with aqueous detergent and deionized water alone is acceptable. If this waste minimization project is successful and acid is eliminated from the reservoir-rinsing procedure, the Rocky Flats Plant will reduce the annual amount of hazardous acid waste currently generated at the plant by about 5 percent. The tangible benefits that are anticipated from this process change are the savings in process-related and waste management costs. Process-related savings in manpower was estimated at about $57,000 per year. Larger savings, however, will most likely be associated with the handling, treatment, storage, and disposal of the 800,000 gallons of hazardous acid waste generated in the process each year. These costs could not be determined for the test case, but qualitative information describing these benefits was collected.

The primary risk (or, more precisely, the most damaging potential consequence) associated with changing the existing acid rinsing procedure is that reservoirs may experience rinsing-induced welding failures or develop permeation problems while in the weapons stockpile. Reservoirs are used in all current weapons systems and all reservoirs are rinsed using the same process. Therefore, any change to the rinsing process introduces a potential common-mode failure that could have widespread consequences. The potential consequences of reservoir failure in the stockpile are very large.

Pinellas Test Case Study -- Magnetic Component Potting

The second proposed waste minimization process change evaluated in the test case involves the development and testing of a less hazardous material to replace a substance suspected to be a human carcinogen currently used in the potting of magnetic components at the Pinellas Plant. Although this process change will not decrease the rate at which hazardous waste is generated at the plant, a reduction in toxicity will mitigate present and future human health and environmental risks.

The Pinellas Plant produces electronic and neutronic components used in many nuclear weapons systems. One of the procedures at the plant involves the potting (encapsulation) of four types of components to form subassemblies: magnetics, neutron generators, thermal batteries, and transducers. Potting is a manual operation performed by workers under fume hoods and wearing gloves and masks. The potting material, which is a mixture of an epoxy, a filler material, and a curing agent, is mixed by the same workers performing the potting operation. The curing agent, called Shell Z hardener, contains methylenedianiline (MDA), a compound that has recently been recognized by the EPA as a potentially carcinogenic substance. Based on the EPA findings, the Occupational Safety and Health Administration (OSHA) has established extremely low worker-exposure limits for MDA. Although the potting operation using Shell Z hardener could continue if stricter handling procedures were followed (e.g., additional protective clothing, respirators, mandatory showers, etc.), the management of the Pinellas Plant is committed to replacing Shell Z hardener with a less hazardous material.

If a new potting material using Ethacure 100 can be developed for magnetic components, a suspected carcinogen will be eliminated from the workplace and the risks to human health and the environment will be reduced. The toxicity of DETDA, the active ingredient in Ethacure 100, is considered low to moderate if ingested internally. Incidental contact with the skin produces no noted health effects. Furthermore, preliminary test results indicate that DETDA is non-carcinogenic, a marked improvement over the MDA used in Shell Z hardener. An ancillary benefit attributable to the reduced health risk to employees is the improvement in worker relations. In addition, workers have expressed concerns that m-phenyldiamine (MPDA), an offgas produced by MDA that has discolored the walls of the potting area, might pose an unrecognized health risk. Elimination of MDA

and MPDA from the workplace will likely bolster worker morale and productivity.

As with all potentially significant process changes, the most threatening risk is an unforeseen failure that could occur after the weapons are placed in the stockpile. Potted magnetic components are used in many different systems in all nuclear weapons. Changing potting materials introduces possible common-mode failures to all newly-produced weapons. Moreover, magnetic components are frequently used in applications where failures can only be detected by stockpile sampling and testing programs. If a new potting material causes the failure of magnetic components while in the stockpile, not only must a new recipe be developed (or the previous recipe reinstated), but all affected weapons will most likely be returned to the production facilities for disassembly, examination, and retrofitting. Although nuclear material contamination will not occur if magnetic components fail, the financial, military, and political consequences of such a possibility are very large.

TEST CASE RESULTS

The evaluation and prioritization methodology was applied to the two proposed waste minimization projects to demonstrate the process and to identify possible improvements in the methodology. After the evaluation criteria and summary findings were developed and assigned relative importance, three major activities were performed in the test case:

1. Proposal data were translated into constituent, fractional scores based on the summary finding responses,

2. Summary finding scores and evaluation criteria weighting factors were combined to obtain individual scores for the top-level criteria of each proposal, and

3. A final score was developed for each proposal.

The Expert Choice software produced a final score for each proposal by combining the summary finding scores with the weighing factors assigned to the evaluation criteria. In addition, individual scores for the top-level criteria were calculated for each proposal. The final scores in the test case demonstration were 0.35 for the Rocky Flats Plant acid elimination proposal and 0.24 for the Pinellas Plant potting material replacement proposal. The scores are normalized values on a scale of 0 to 1, where a "1" represents the best possible score.

The principal reason why the Rocky Flats proposal is more attractive than the Pinellas proposal is that it provides greater environmental, safety, and health benefits. The Rocky Flats proposal also scores slightly higher in the areas of Effect on Intangibles and Technical Risk. As we have stated previously, however, these judgments are based on the authors' interpretations of the proposal data, the authors' opinions regarding the summary finding responses, and the relative importance assigned by the authors to the evaluation criteria and summary findings. The final scores might change significantly if other evaluators performed the scoring and weighting, or if additional data describing the proposals were available.

CONCLUSIONS AND RECOMMENDATIONS

This paper describes a formal process for selecting, from a diverse set of proposed waste minimization activities, those activities that provide the greatest benefit to DOE. A methodology for evaluating and prioritizing proposals was developed to illustrate how the selection process works and what types of data are required to characterize waste minimization activities. It is clearly impossible to remove all aspects of subjective judgment from the proposal selection process. With this important consideration in mind, the methodology presented is put forth to enhance, not replace, the traditional DOE decision-making process.

The following conclusions and recommendations are based on the experience gained during the methodology development process and test case application.

1. The structured evaluation criteria and evaluation process described in this paper provide documented, defensible records to support the decision-making and budget allocation process. The reasons for ranking one proposal higher than another can be determined explicitly from the results of the evaluation.

2. A cost data base should be developed to support proposal preparation and evaluation. Data from previous efforts should be collected and processed to provide a resource supporting future efforts. Guidance should be developed for cost estimation and for ensuring that sources of cost data used in proposals are identified adequately and that assessments are done properly.

3. A mechanism should be established to allow feedback from proposers and other participants in the selection process to ensure the continued improvement of the evaluation and prioritization process.

4. Waste minimization within the nuclear weapons complex, especially activities involving changes to manufacturing processes, is difficult to justify solely on a cost basis. Many expected costs and cost savings are extremely difficult to estimate due to the large fixed costs associated with nuclear weapon manufacturing. Most waste minimization initiatives in this area will not be economically attractive projects using traditional financial analysis techniques.

In summary, a comprehensive evaluation and prioritization methodology has been developed and tested. With relatively minor refinements, this methodology can be immediately useful to DOE Environmental Restoration and Waste Management and Defense Program organizations in preparing, evaluating, and prioritizing waste minimization proposals.

A Sandia Report has been written documenting this effort.[7]

POSTSCRIPT

Since this work was published, the methodology has been used in two applications. 1) In late FY 90 the DOE initiated a Waste and Hazard Reduction program in the nuclear weapons complex. A simplified version of the methodology discussed in this paper, with elements from a similar effort by Lawrence Livermore National Laboratory, was successfully used by the DOE and its contractors to prepare, evaluate, and prioritize over 200 waste minimization and hazard reduction projects. Those projects were mainly R&D efforts addressing anticipated ES&H compliance issues; thus, economic feasibility was not explicitely addressed.

2) The DOE has recently developed and distributed a draft Model Process Waste Assessment Plan which outlines a disciplined methodology for collecting data for process assessments and for evaluating waste minimization options. The procedures for evaluating and prioritizing options are those described in this paper and the complete report.[7]

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